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## (54) Aircraft air conditioning system

(57) An air cycle air conditioning system has an air expansion turbine 12 arranged for supplying a flow of turbine expanded air for conditioning a heat load 19. Water extracted at 16 from high pressure supply air upstream of the air expansion turbine 12 is injected into the coolant flow entry 17 of a heat exchanger 15

arranged for receiving the flow of turbine expanded air after this air has extracted heat from the heat load 19 e.g. a cabin. This enhances the cooling efficiency of the system by making use of the latent heat of evaporation of the extracted water when this water is returned to the system in a region where it provides a coolant function. The heat exchanger 15 cools high pressure supply air between the compressor 13 and turbine 12 but, in an alternative embodiment, the heat exchanger receiving injected water into the coolant flow entry is in heat exchange relationship with a fluid circulating in a separate loop to cool a further heat load.

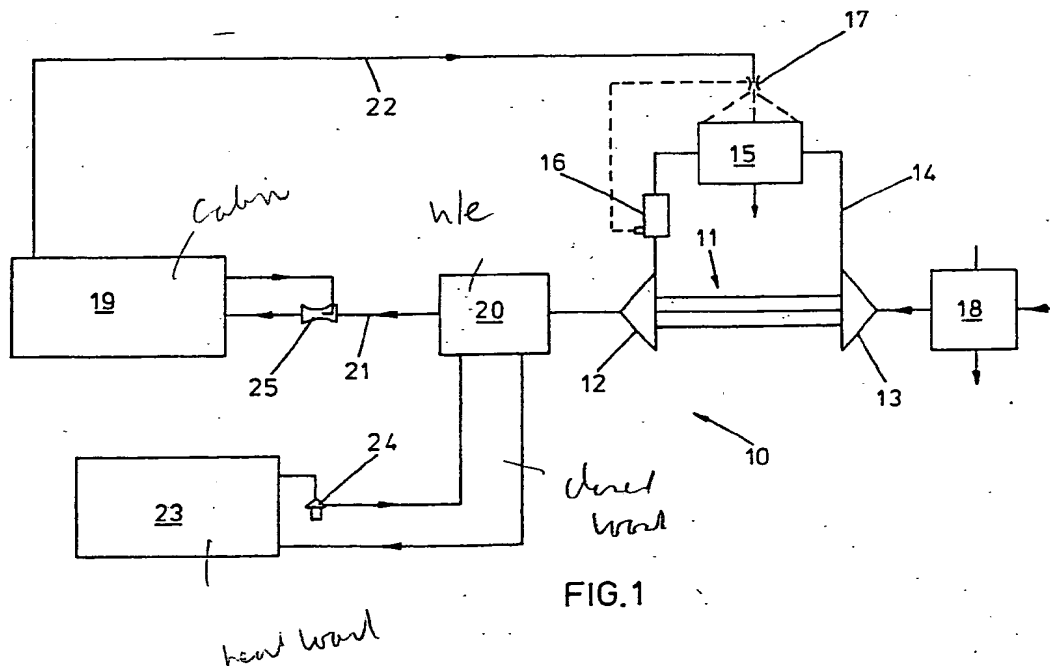


FIG.1

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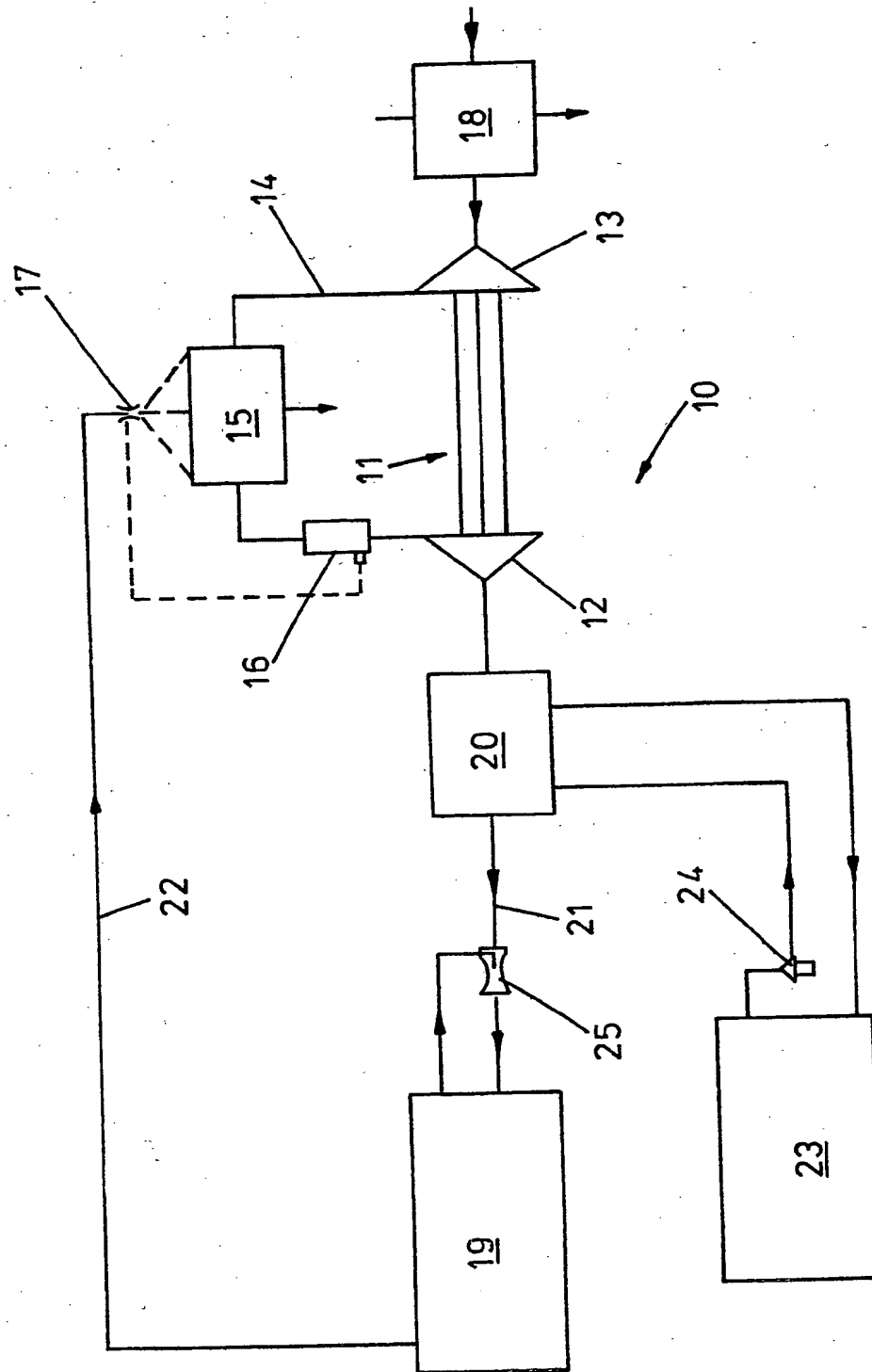


FIG.1

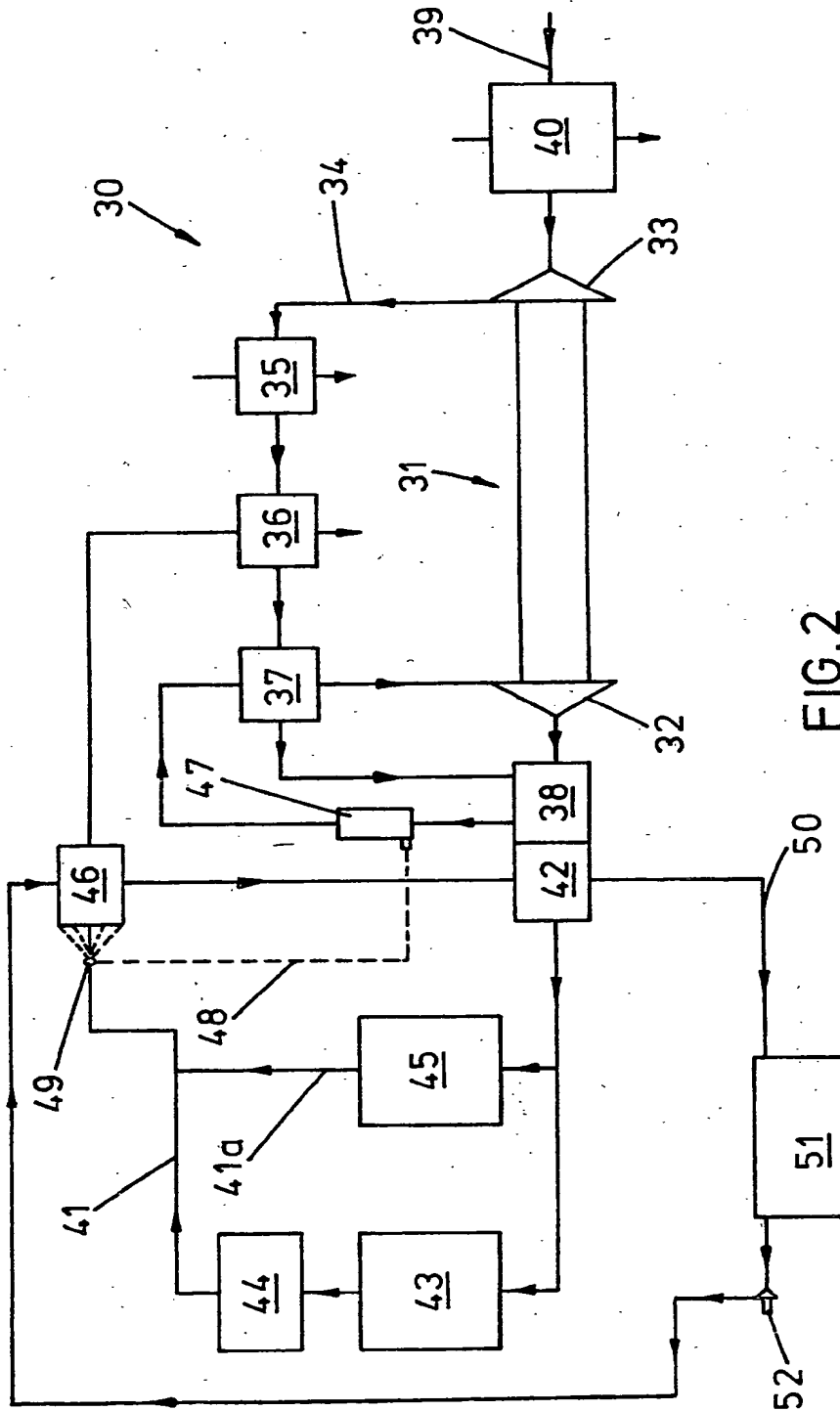


FIG. 2

## SPECIFICATION

## Air cycle air conditioning system

This invention relates to air cycle air conditioning systems.

- 5 Air cycle air conditioning systems are extensively used in aircraft and accomplish cooling of a suitable supply of air at an elevated temperature by effecting expansion of that air through a turbine and by heat transfer to one or  
10 more heat exchangers; however, there is a continuing requirement for air conditioning systems to provide greater cooling capacity for no greater demand on engine bleed air.

- It is well known that as air is expanded through  
15 a turbine its temperature is reduced and that sub-zero temperatures, i.e. below 0°C, can be obtained. It is also well understood that because of variations in the level of humidity of the supplied air, which is generally derived from the  
20 atmosphere, ice may or may not be formed at the turbine outlet according to the prevailing atmospheric conditions. Consequently in order to avoid impairment of the performance of a turbine and thus the system of which it is a part, owing to  
25 the formation of ice, it is often arranged that the temperature of the air delivered by the turbine shall be at substantially 0°C, or alternatively, that icing shall be combatted by warming the turbine outlet structure to prevent ice accretion thereon. It  
30 is generally the practice to include means in such air conditioning systems for extracting water from the air supplied to the expansion turbine in order to produce conditions that are less favourable to the formation of ice. Also, it is well understood  
35 that by spraying water into cooling air at the entry to a heat exchanger more efficient heat extraction from the charge air is obtained. In consequence, many air cycle air conditioning systems are known in which water that is extracted from the supply  
40 air is injected into ram-air coolant of precoolers and primary heat exchangers for cooling the supply air.

- Recent developments have provided improved water extraction in such systems by including  
45 means of extraction, referred to as high-pressure water separation, which condenses water upstream of the turbine inlet, where the supply air is at high system pressure and consequently the advantage of higher dew-point temperature is  
50 available. In such means a condenser heat exchanger is arranged to pass supply air feeding to an air expansion turbine as charge flow and then to pass the same air as coolant flow upon its discharge from the turbine. Such arrangement  
55 allows the use of a turbine outlet temperature substantially below 0°C but because it does not remove all of the water, the condenser outlet temperatures are normally limited to a minimum of about -10°C. If, after use, the conditioned air  
60 leaves the system at, typically, 50°C the gain in cooling capacity from the use of air delivered at -10°C, as compared to conventional systems in which the air is delivered at just above 0°C, is small.

- 65 However, of such systems as we are aware, there is failure to use the extracted water in the most efficient manner, inasmuch as the latent heat of evaporation is not used to its full potential.

- According to the present invention an air cycle  
70 air conditioning system includes an air expansion turbine for supplying a flow of expanded air for conditioning purposes, a heat exchanger having a coolant flow entry arranged for receiving the flow of turbine-expanded supply air after this air has  
75 subtracted heat from a heat load, means for extracting water from high pressure supply air upstream of the air expansion turbine, and means for injecting the extracted water into the coolant flow entry of the heat exchanger.

- 80 In one air cycle air conditioning system in accordance with the present invention pre-cooled air is passed through a compressor on a common shaft with the air expansion turbine and then to the turbine inlet by way of the charge side of the  
85 heat exchanger in which it is cooled by the flow of turbine expanded supply air after this air has extracted heat from a heat load, and the water extracted from the high pressure supply air upstream of the turbine inlet is injected into the  
90 turbine-expanded supply air as this air enters coolant flow entry of the heat exchanger.

- In this system the latent heat of evaporation of the water removed is used to condense the water in the high pressure air supplied by the  
95 compressor to the turbine, thus giving performance substantially equivalent to that obtainable with dry air over the ambient humidity range.

- In another air cycle air conditioning system in  
100 accordance with the present invention the flow of turbine expanded supply air, after having extracted heat from a heat load such as a compartment, is passed through the heat exchanger so as to be in heat exchange relationship with fluid circulating in a separate loop to cool a further heat load, and the  
105 water extracted from the high pressure supply air upstream of the turbine inlet is injected into the turbine-expanded supply air as this air enters the coolant flow entry of the heat exchanger.

- 110 Whereas known systems which include means for extracting water from high pressure air upstream of the turbine inlet inject the extracted water into the coolant entry of a ram air heat exchanger so that the effectiveness of the  
115 evaporation of the water is normally limited by the high coolant-to-charge flow ratio, the present invention provides a system in which the two mass flows through the heat exchanger into which the extracted water is injected are the same and  
120 thereby provides an optimum heat transfer characteristic in realisation of the best use of the latent heat of evaporation of the extracted water.

- The invention will now be further described by way of example with reference to the  
125 accompanying drawings, in which:—

Figure 1 is a diagrammatic illustration of an air cycle air conditioning system in accordance with one embodiment of the invention; and

Figure 2 is a diagrammatic illustration of an air

cycle air conditioning system in accordance with another embodiment of the invention.

Referring to Figure 1, an air cycle air conditioning system 10 according to the invention includes a turbo-compressor arrangement 11 of bootstrap form, comprising a cold air expansion turbine 12 installed in operable disposition with a radial compressor 13 by means of a fluid connection 14 and a common shaft. The connection 14 conveys air from the compressor 13 to the turbine 12 by way of the charge side of a heat exchanger 15 and thence to a swirl type water extractor 16. The water extractor 16 is connected with an injector device 17 which is arranged to spray water from the sump of the water separator 16 into the entry of the coolant side of the heat exchanger 15. The compressor 13 is arranged to receive pressurised supply air fed through a precooler heat exchanger 18 from a source such as a high or intermediate pressure stage of an aircraft turbine engine (not shown). The outlet of the turbine 12 is connected to the inlet of a compartment or cabin 19 by way of the coolant side of a heat exchanger or load-heat-sink 20; which side forms part of a conduit arrangement 21. A conduit 22 for discharging outflow of turbine-expanded supply air from the compartment 19 is connected to the coolant side of the bootstrap heat exchanger 15 and from there to overboard. The charge side of the heat exchanger 20 forms part of a closed recirculation circuit that includes a heat-load 23, such as an electronics equipment bay. The fluid within the circuit may be gaseous or liquid, and is circulated by a fan or pump 24 as appropriate. The conduit arrangement 21, when feeding to a cabin 19, preferably includes a flow inducer arrangement 25 for recirculating some cabin air.

In operation of the system 10 pressurised air from the supply source (not shown) is cooled in passing through the precooler 18 prior to entering the bootstrap turbo-compressor arrangement 11 from which it is expanded to reach sub-zero temperatures of, say,  $-50^{\circ}\text{C}$  to  $-60^{\circ}\text{C}$  before entering the load heat exchanger 20. A considerable heat transfer occurs in this heat exchanger in dissipation of the heat load 23 such that the temperature of the turbine-expanded supply air at its outlet may be, say,  $0^{\circ}\text{C}$  to  $-10^{\circ}\text{C}$  and, where this is fed to a cabin 19, requires to be raised further to a level acceptable to passengers. This is achieved by recirculating some cabin air by way of entrainment by the flow inducing arrangement 25 disposed upstream of the cabin entry. The turbine-expanded supply air after discharge from the cabin 19 passes by way of conduit 22 to the heat exchanger 15 in which it provides the coolant for the high pressure supply air subsequent to this being worked upon by the compressor 13. The efficiency of this arrangement for heat transfer is improved by spraying into the turbine-expanded supply air at the coolant flow entry of the heat exchanger 15, all the water previously extracted from the high pressure supply air by the water separator 16. As substantially all

the water is extracted from the supply air and then returned thereto the most efficient use of the latent heat for the evaporation of the water is enabled, thus giving performance substantially equivalent to that obtainable with dry air over the ambient humidity range. This together with the use of substantially sub-zero air as a cooling medium minimises the requirement to bleed air from the aircraft engine.

Referring to Figure 2, an air cycle air conditioning system 30, developed from that above described and providing greater self-regulation and an inherent ability to self-adjust appropriate to pertaining humidity conditions of the pressurised supply air, includes a bootstrap-type turbo-compressor and heat exchanger arrangement 31 comprising an air expansion turbine 32 and radial compressor 33 mounted on a common shaft and having the compressor outlet connected to the turbine inlet by way of a conduit arrangement 34 that includes, in downstream order, the charge sides of an intercooler 35, a regenerative heat exchanger 36, a reheater 37, a condenser heat exchanger 38 and the coolant side of the reheater 37. A conduit means 39 connects the inlet of the compressor to a pressurised air supply source (not shown), such as an aircraft engine bleed, by way of a precooler 40. The outlet of the turbine 32 is connected by a conduit arrangement 41 to the coolant sides of the condenser 38 and a heat exchanger 42 and thence to a plurality of compartments, that may comprise a cabin 43 and two equipment bays 44, 45, and from there to overboard by way of the coolant sides of a heat exchanger 46 and the regenerative heat exchanger 36. One equipment bay 45 is situated in a branch conduit 41a that bypasses the cabin 43 and bay 44. Water extractor means 47, preferably of the form having fixed swirl vanes, is included in the conduit arrangement 34 at the outlet of the condenser 38 and is connected by tubing 48 to an injector device 49 for spraying water into the coolant flow entry of heat exchanger 46. The charge sides of the heat exchangers 42 and 46 form part of a closed recirculatory cooling circuit 50 which includes a heat load 51. The coolant fluid within the circuit 50 may be gaseous or liquid and is recirculated by a fan or pump 52 as appropriate. The coolant flows for the precooler 40 and the intercooler 35 may be derived from any suitable source and, in an aircraft application, conveniently are provided by ram air.

In operation of the embodiment illustrated in Figure 2, assuming an aircraft application, pressurised supply air is fed at a predetermined pressure to the inlet of the compressor 33 by way of conduit means 39 and the precooler 40. In a manner usual to bootstrap systems the temperature of the supply air is raised during its compression and then cooled in its passage through the conduit arrangement 34 where in this system cooling is successively provided in the intercooler 35 by ram air, the regenerative heat exchanger 36 by the supply air which is

imminently discharging from the system 30; whilst in the reheater 37 heat is transferred from a region of the supply air upstream of the condenser 38 to one downstream thereof whereby it is reheated prior to entry to the turbine wherein it is expanded in full. Condensate is removed from the supply air at the condenser outlet by the water extractor 47.

In conditions of high humidity the temperature of the turbine-expanded supply air discharging from the condenser 38 will not be substantially below freezing, say  $-10^{\circ}\text{C}$ , owing to the effect of condensing the water in the air; whilst in conditions of low humidity the temperature will be substantially lower, say  $-40^{\circ}\text{C}$ , owing to the reduced condensation requirement. This discharging turbine-expanded supply air feeds, as the coolant flow, through the heat exchanger 42 wherein it gains heat from the cooling fluid of the closed circuit 50 before passing to the cabin 43 and the bay 44 and at the discretion of a temperature control valve (not shown) to the bay 45 in bypass 41a. The turbine-expanded supply air, as outflow from the cabin and bays 43, 44, 45 respectively, is fed as coolant to the heat exchanger 46 which has the injector device 49 spraying into its entry the water extracted by the water extractor 47. The amount of this water increases, with increasingly humid atmospheric conditions and consequently the cooling effect on the charge flow, i.e. the circulating fluid in the cooling circuit 50 increases and, in conditions of high humidity, not all the injected water is evaporated in heat exchanger 46. Water that is not so evaporated is carried over into the coolant side of the regenerative heat exchanger 36 of the bootstrap turbo-compressor arrangement 31 where it is then evaporated before the turbine-expanded supply air leaves the system.

The fluid in the closed cooling circuit 50 is circulated by the fan or pump 52 whereby heat that is generated at the heat load 51 is dissipated by transfer to the turbine-expanded supply air flowing through the heat exchangers 42 and 46.

Thus for supply air having conditions of high humidity a substantial proportion of the cooling capacity is achieved by evaporation of water in heat exchanger 46 whilst for conditions of low humidity a substantial proportion of the cooling is achieved by the cold dried air in heat exchanger 42.

In conditions of high humidity, it is because evaporation is not completed in heat exchanger 46 and final evaporation occurs in the regenerative heat exchanger 36, so providing this with greater cooling capacity and consequently a higher condensation rate in the condenser 38, that the flow of supply air to the turbine 32 can be maintained in a sufficiently dried state to permit substantial sub-zero temperatures at the turbine outlet. Known temperature control means (not shown) are incorporated in the system for regulation of variable conditions therein and demand thereon during operation in order to maintain maximum working efficiency.

It will be understood, from the foregoing disclosures, that the efficiency of earlier systems can be enhanced by the more efficient use of the latent heat of evaporation by return of all the water extracted from the supply air in a high pressure region of the system to this same air in a region where it provides a coolant function and that by enabling the use of air at substantial sub-zero temperature as a cooling medium the requirement to bleed supply air from a turbine engine can be minimised for a given system cooling capacity.

Of course, the embodiments of the invention hereinbefore described with reference to and as shown in the accompanying drawings are by way of example only and modifications and alternatives may be introduced. For example, various means of flow regulation, such as a turbine having variable flow nozzles, can be incorporated and/or alternative bypass arrangements for balancing the system cooling capacity to the various heat loads may be included.

#### CLAIMS

1. An air cycle air conditioning system including an air expansion turbine for supplying a flow of expanded air for conditioning purposes, a heat exchanger having a coolant flow entry arranged for receiving the flow of turbine-expanded supply air after this air has subtracted heat from a heat load, means for extracting water from high pressure supply air upstream of the air expansion turbine, and means for injecting the extracted water into the coolant flow entry of the heat exchanger.
2. An air cycle air conditioning system as claimed in Claim 1, wherein the heat exchanger is arranged to be in heat exchange relationship with high pressure supply air flowing from a compressor to the air expansion turbine.
3. An air cycle air conditioning system as claimed in Claim 2, wherein the heat load comprises a compartment to which turbine-expanded supply air flows for conditioning purposes by way of the coolant side of a heat load heat exchanger which is arranged to be in heat exchange relationship with a fluid circulating in a closed circuit that includes a further heat load.
4. An air cycle air conditioning system as claimed in Claim 1, wherein the heat exchanger is arranged to be in heat exchange relationship with a fluid circulating in a loop to cool a further heat load.
5. An air cycle air conditioning system as claimed in Claim 4, wherein the water extraction means is provided downstream of a condenser heat exchanger in a conduit arrangement connecting a radial compressor outlet with the air expansion turbine inlet.
6. An air cycle air conditioning system as claimed in Claim 5, wherein the conduit arrangement includes a regenerative heat exchanger connected with the outlet of the

coolant side of the heat exchanger so as to receive the flow of turbine-expanded supply air flowing from the coolant side of the heat exchanger after injection of the extracted water.

5 7. An air cycle air conditioning system substantially as described with reference to and

shown in Figure 1 of the accompanying drawings.

8. An air cycle air conditioning system substantially as described with reference to and as

10 shown in Figure 2 of the accompanying drawings.

9. Every novel feature and every novel combination of features disclosed herein.

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